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TITLE: Spin-Valve Magnetoresistive
                  Element Having Fixed Magnetic
                  Layer of Epitaxial Laminate Including
                  Magnetic Layer and Nonmagnetic
                  Layer

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SPIN-VALVE MAGNETORESISTIVE ELEMENT HAVING FIXED MAGNETIC LAYER OF EPITAXIAL LAMINATE INCLUDING MAGNETIC LAYER AND NON-MAGNETIC LAYER

5   This application claims the benefit of priority to Japanese Patent Application No. 2003-048694, herein incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

10 1. Field of the Invention

The present invention relates to magnetic sensors each having a free magnetic layer, a non-magnetic material layer, and a fixed magnetic layer, and more particularly, relates to a magnetic sensor fixing the magnetization of a fixed

15 magnetic layer by uniaxial anisotropy thereof.

2. Description of the Related Art

Among magnetic sensors mounted in magnetic read and write devices, a spin-valve magnetic sensor exploiting a giant magnetoresistive (GMR) effect is the most widely used.

20   A spin-valve magnetic sensor comprises a laminate formed of a ferromagnetic film called a fixed magnetic layer and a ferromagnetic soft magnetic film called a free magnetic layer with a non-magnetic material film called a non-magnetic material layer interposed therebetween.

25   The magnetization of the free magnetic layer is oriented in a particular direction by a longitudinal bias magnetic field caused, for example, by hard bias layers made of a soft magnetic material. The magnetization direction of the

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free magnetic layer is sensitive and is changed by an external magnetic field supplied from a recording medium. On the other hand, the magnetization of the fixed magnetic layer is fixed in a direction intersecting the magnetization

5   direction of the free magnetic layer.

Electrical resistance is changed by the relationship between the fixed magnetization direction of the fixed magnetic layer and the change in magnetization direction of the free magnetic layer. Using the change in voltage or

10   change in current caused by this change in electrical resistance, a leak magnetic field from a recording medium may be detected.

Heretofore, the fixed magnetic layer is formed on an antiferromagnetic layer made of an antiferromagnetic

15   material such as PtMn so that an exchange coupling magnetic field is generated therebetween, thereby fixing the magnetization of the fixed magnetic layer.

The exchange coupling magnetic field generated at an interface between the antiferromagnetic layer and the fixed

20   magnetic layer can be sufficiently increased so as to prevent the change in magnetization direction of the fixed magnetic layer caused by a magnetic field applied in a production process or a leak magnetic field from a recording medium. In addition, since the antiferromagnetic layer

25   itself generates no magnetic field outside, the magnetic sensor may be designed easily.

However, in order to generate a sufficiently large exchange coupling magnetic field at the interface between

the antiferromagnetic layer and the fixed magnetic layer,
the antiferromagnetic layer must have a thickness of
approximately 200 Å.

An antiferromagnetic layer having a large thickness
5   present in a laminate forming a magnetic sensor primarily
causes a shunt loss in a sense current. In order to
increase the recording density of a recording medium, the
output of the magnetic sensor must be improved. However,
the shunt loss described above causes deterioration in the
10 magnetic sensor output, thereby inhibiting such an
improvement.

In addition, for efficiently reading a record signal to
be detected, shield layers each formed of a soft magnetic
material are provided at a top and a bottom side of a
15 magnetic sensor. To increase the recording density of the
recording medium, it is necessary to decrease the distance
between the top and the bottom shield layers. However, the
large thickness of the structure due to the presence of the
thick antiferromagnetic layer makes it difficult to decrease
20 the distance between the top and the bottom shield layers.

Accordingly, as shown in Fig. 14, a magnetic sensor has
been proposed in which an antiferromagnetic layer is not
formed and in which the magnetization of a fixed magnetic
layer is fixed by uniaxial anisotropy thereof.
25 In the magnetic sensor shown in Fig. 14, on a lower gap
layer 1 made of an insulating material such as alumina, a
multilayer film T is provided which is composed of an
underlying layer 2; a fixed magnetic layer 3 having a

synthetic ferrimagnetic structure composed of a first
magnetic layer 3a and a second magnetic layer 3c with a non-
magnetic interlayer 3b interposed therebetween; a non-
magnetic material layer 4; a free magnetic layer 5; and a
5   protective layer 6 in that order from the bottom side. In
addition, on two sides 7 of the multilayer film T, bias
underlying layers 8, hard bias layers 9, and electrode
layers 10 are formed.

    In the magnetic sensor shown n Fig. 14, an
10   antiferromagnetic layer is not provided on the fixed
magnetic layer 3, and by the uniaxial anisotropy of the
fixed magnetic layer 3 itself, the magnetization thereof is
fixed in a Y direction in the figure. Accordingly, since
the shunt loss can be decreased as compared to that of a
15   related magnetic sensor provided with an antiferromagnetic
layer, a magnetic field detection output of the magnetic
sensor can be improved by 20% to 30%. In addition, since
the distance between the shield layers provided at the top
and the bottom sides of the magnetic sensor can be decreased,
20   the recording density of a recording medium can be increased.

    A magnetic sensor as shown in Fig. 14 has been disclosed
in Japanese Unexamined Patent Application Publication No. 8-
7235 (pp. 8 and 9, and Fig. 5) and Japanese Unexamined
Patent Application Publication No. 2000-113418 (pp. 7 and 8,
25   and Figs. 4 to 7)

    In the magnetic sensor disclosed in Japanese Unexamined
Patent Application Publication No. 8-7235, on a buffer layer
62 of tantalum used as an underlayer, a pinned ferromagnetic

layer 70 is provided. The pinned ferromagnetic layer 70 is

a laminate composed of a first cobalt (Co) film 72 and a

second cobalt (Co) film 74 with a ruthenium (Ru) film 73

interposed therebetween. The magnetizations of the first

5   cobalt (Co) film 72 and the second cobalt (Co) film 74 are

fixed by respective anisotropic magnetic fields thereof.

The first cobalt (Co) film 72 and the second cobalt (Co)

film 74 are antiferromagnetically coupled with each other

and are magnetized antiparallel to each other.

10   However, it was found that, in the structure as that

disclosed in Japanese Unexamined Patent Application

Publication No. 8-7235 in which the Co films are provided on

the buffer layer made of tantalum, the magnetization

direction of the pinned ferromagnetic layer 70 cannot be

15   appropriately fixed. This fact has also been disclosed in

Japanese Unexamined Patent Application Publication No. 2000-

113418.

        The magnetic sensor disclosed in Japanese Unexamined

Patent Application Publication No. 2000-113418 was made in

20   order to solve the problem of Japanese Unexamined Patent

Application Publication No. 8-7235. In this magnetic sensor,

ferromagnetic films of a laminated ferrimagnetic fixed layer

are formed using CoFe or CoFeNi, thereby improving the

induced anisotropy.

25   In Japanese Unexamined Patent Application Publication No.

2000-113418, the structure in which an underlying layer made

of tantalum (Ta) is provided under the laminated

ferrimagnetic fixed layer is also described; however,

according to experimental results (Figs. 4 to 7 in Japanese

Unexamined Patent Application Publication No. 2000-113418)

obtained with and without the use of the Ta underlying layer,

it has been shown that when a CoFe alloy is used for the

5   ferromagnetic layer, the change in magnetoresistance and the

coercive force are increased when the Ta underlying layer is

not provided.

In order to increase the induced anisotropy of the

laminated ferrimagnetic fixed layer, the use of a CoFe alloy

10   for the ferromagnetic film and the use of a ferromagnetic

layer having a positive magnetostriction constant are

disclosed in Japanese Unexamined Patent Application

Publication No. 2000-113418.

One factor in fixing the magnetization of a self-fixed

15   magnetic layer is the uniaxial anisotropy derived from the

magnetoelastic energy of the fixed magnetic layer. In

particular, it is useful to optimize the magnetostriction of

the fixed magnetic layer. However, in Japanese Unexamined

Patent Application Publication No. 2000-113418, a mechanism

20   for optimizing the magnetostriction of the fixed magnetic

layer has not been discussed, nor has a particular structure

for optimizing the magnetostriction of the fixed magnetic

layer has been described.

25. SUMMARY OF THE INVENTION

The present invention provides optimization of the

magnetostriction of the fixed magnetic layer. A magnetic

sensor having a self-fixed magnetic layer and a mechanism of

controlling the magnetostriction of the fixed magnetic layer
are disclosed to appropriately control the magnetostriction.
By exploiting the mechanism described above, a magnetic
sensor which can tightly fix the magnetization of a fixed

5   magnetic layer can be provided by appropriately selecting a
material for a non-magnetic film which is in contact with
the fixed magnetic layer.

A magnetic sensor of the present invention comprises a
fixed magnetic layer, a free magnetic layer laminated

10   thereto, a non-magnetic material layer interposed between
the fixed magnetic layer and the free magnetic layer, and a
non-magnetic metal layer composed of a platinum-manganese
(PtMn) alloy or an X-Mn alloy (where X is at least one
selected from the group consisting of platinum (Pt),

15   palladium (Pd), iridium (Ir), rhodium (Rh), ruthenium (Ru),
osmium (Os), nickel (Ni), and iron (Fe)). In the magnetic
sensor described above, the fixed magnetic layer is a
laminate comprising a plurality of magnetic layers with a
non-magnetic interlayer interposed therebetween, a first

20   magnetic layer among the plurality of magnetic layers, which
is provided at a position farthest from the non-magnetic
material layer, is in contact with the non-magnetic metal
layer, a crystal of the non-magnetic metal layer and a
crystal of the first magnetic layer are placed in an

25   epitaxial state or a heteroepitaxial state, and the fixed
magnetic layer has an open end surface at a face opposing a
recording medium.

An epitaxial state is a state in which the types of

crystal lattice (e.g. fcc, bcc, hcp) of the nonmagnetic

metal layer and the first magnetic layer are the same and

the atoms are substantially aligned, albeit the crystal is

deformed at the boundary due to the difference in lattice

5   constants of the different materials. Conversely, a

heteroepitaxial state is a state in which the types of

crystal lattice of the nonmagnetic metal layer and the first

magnetic layer are different while the atoms are

substantially aligned and the crystals are deformed, as in

10   the epitaxial state. A non-epitaxial state is a state in

which dislocations of the crystal at the boundary relieve

strain at the boundary and the atoms are not substantially

aligned, no matter whether the crystal lattice types of the

nonmagnetic metal layer and the first magnetic layer are the

15   same or different.

The fixed magnetic sensor of the present invention is a

magnetic sensor in which the magnetization of the fixed

magnetic layer is fixed by the uniaxial anisotropy thereof

(hereinafter, this magnetic sensor is referred to as a

20   "self-fixed type magnetic sensor" in some cases).

Accordingly, since the shunt loss can be decreased as

compared to that of a magnetic sensor composed of an

antiferromagnetic layer having a large thickness of 200 Å,

the magnetic field detection output of a magnetic sensor can

25   be improved by 20% to 30%. In addition, the distance

between shield layers provided at a top and a bottom side of

the magnetic sensor is decreased, which allows an even

higher recording density recording medium to be achieved.

Factors that determine a magnetic anisotropic magnetic field of a ferromagnetic film include the crystal magnetic anisotropy, induced magnetic anisotropy, and a magnetoelastic effect. Among these, in a film having a polycrystalline structure in which crystal grains are randomly oriented, it is difficult to obtain uniaxial anisotropy using the crystal magnetic anisotropy. On the other hand, when a magnetic field is applied to a film in one direction when it is formed or is processed by heat treatment, the uniaxial anisotropy is obtained from the induced magnetic anisotropy, and when a uniaxial stress is applied, due to the magnetoelastic effect, the uniaxial anisotropy is obtained.

Of the induced magnetic anisotropy and the magnetoelastic effect, which determine the uniaxial anisotropy fixing the magnetization of the fixed magnetic layer, the magnetoelastic effect is exploited in the present invention.

The magnetoelastic effect is controlled by the magnetoelastic energy. The magnetoelastic energy is defined by a stress applied to the fixed magnetic layer and the magnetostriction constant thereof.

In the present invention, since the end surface of the fixed magnetic layer at a face opposing a recording medium is open, the symmetry of stresses is no longer maintained, and as a result, a tensile stress is applied to the fixed magnetic layer in a height direction (the direction normal to the opposing face mentioned above) of the sensor.

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In the present invention, the magnetoelastic energy is
increased by increasing the magnetostriction constant of the
fixed magnetic layer, and in accordance with this increase,
the uniaxial anisotropy of the fixed magnetic layer is

5   enhanced. When the uniaxial anisotropy of the fixed
magnetic layer is enhanced, since the magnetization of the
fixed magnetic layer is tightly fixed in a predetermined
direction, the output of the magnetic sensor is increased,
and the stability and the symmetry of the output are also

10   improved.

In particular, since the first magnetic layer among the
plurality of magnetic layers forming the fixed magnetic
layer described above is in contact with the non-magnetic
metal layer so as to form an epitaxial or a heteroepitaxial

15   state, the non-magnetic metal layer being composed of an X-
Mn alloy (where X is at least one selected from the group
consisting of Pt, Pd, Ir, Rh, Ru, Os, Ni, and Fe), a strain
is generated in the first magnetic layer, and hence the
magnetostriction constant λ of the first magnetic layer is

20   increased.

When composed of an X-Mn alloy (where X is at least one
selected from the group consisting of Pt, Pd, Ir, Rh, Ru, Os,
Ni, and Fe), the non-magnetic metal layer may have a face-
centered cubic (fcc) structure in the entire region thereof

25   or in the vicinity of an interface at the first magnetic
layer side of the fixed magnetic layer, and when an
appropriate seed layer formed of NiFeCr or the like is
provided under the non-magnetic metal layer, equivalent

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crystal planes represented by the {111} plane may be oriented in the direction parallel to the interface.

The non-magnetic metal layer has a thickness of 5 to 50 Å. When the thickness of the non-magnetic metal layer

5   composed of an X-Mn alloy (where X is at least one selected from the group consisting of Pt, Pd, Ir, Rh, Ru, Os, Ni, and Fe) is in the range described above, the crystal structure of the non-magnetic metal layer continuously maintains a face-centered cubic (fcc) structure which is formed in film

10 formation. When the thickness of the non-magnetic metal layer is more than 50 Å, and when a temperature of 250°C or more is applied thereto, the crystal structure of the non-magnetic metal layer is disadvantageously transformed into a CuAuI type regular face-centered tetragonal (fct) structure.

15 However, although the thickness of the non-magnetic metal layer is more than 50 Å, when a temperature at 250°C or more is not applied thereto, the crystal structure of the non-magnetic metal layer continuously maintains a face-centered cubic (fcc) structure which is formed in film formation.

20 When the non-magnetic metal layer composed of an X-Mn alloy (where X is at least one selected from the group consisting of Pt, Pd, Ir, Rh, Ru, Os, Ni, and Fe) has a face-centered cubic (fcc) structure, an exchange coupling magnetic field is not generated at the interface between the

25 non-magnetic metal layer and the first magnetic layer, or even when generated, the exchange coupling magnetic field is extremely weak, and hence the magnetization direction of the first magnetic layer cannot be fixed by the exchange

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coupling magnetic field.

In addition, when the X element content of the X-Mn alloy is 55 to 99 atomic percent, the magnetostriction of the first magnetic layer can be increased.

5   In addition, even when the X element is Pt and the Pt content is 100 atomic percent, the magnetostriction can be increased. However, when the Pt content is 100 atomic percent, since the electrical resistance is decreased, the shunt loss of a sense current is increased, and hence the

10   output is liable to be decreased. Accordingly, by adding one atomic percent of Mn or more, the specific resistance is increased.

The magnetic sensor of the present invention may further comprise bias layers on side portions of the free magnetic

15   layer and fixed magnetic layer, which bias layers supply a longitudinal bias magnetic field to the free magnetic layer.

In the present invention, the first magnetic layer of the fixed magnetic layer may have a face-centered cubic (fcc) structure in the entire region thereof or in the

20   vicinity of an interface at the non-magnetic metal layer side, and equivalent crystal planes represented by the {111} plane may be oriented in a direction parallel to the interface.

As described above, the non-magnetic metal layer of the

25   present invention has a face-centered cubic (fcc) structure in which equivalent crystal planes represented by the {111} plane are oriented in the direction parallel to the interface.

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Hence, when the first magnetic layer has a face-centered cubic (fcc) structure in which equivalent crystal planes represented by the {111} plane are oriented in the direction parallel to the interface, atoms forming the first magnetic

5   layer and atoms forming the non-magnetic metal layer are likely to be aligned with each other.

However, since the nearest interatomic distance of the first magnetic layer in the {111} plane differs from that of the non-magnetic metal layer in the {111} plane by at least

10   a particular value, in the vicinity of the interface between the first magnetic layer and the non-magnetic metal layer, while the atoms forming the first magnetic layer and the atoms forming the non-magnetic metal layer are being aligned with each other, strains are generated in the individual

15   crystal structures. That is, by generating the strain in the crystal structure of the first magnetic layer, the magnetostriction constant λ can be increased.

For example, when composed of Co or Co_xFe_y (where $y \leq 20$ and $x+y=100$ are satisfied), the first magnetic layer of the

20   fixed magnetic layer may have a face-centered cubic (fcc) structure in which equivalent planes represented by the {111} plane are oriented in the direction parallel to the interface.

Alternatively, the first magnetic layer of the fixed

25   magnetic layer may have a body-centered cubic (bcc) structure in the entire region thereof or in the vicinity of the interface at the non-magnetic metal layer side, and equivalent crystal planes represented by the {110} plane be

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oriented in the direction parallel to the interface.

Even when the first magnetic layer has a bcc structure in which equivalent crystal planes represented by the {110} plane are oriented in the direction parallel to the

5   interface, the atoms forming the first magnetic layer and the atoms forming the non-magnetic metal layer become likely to be aligned with each other.

As is the case described above, since the nearest interatomic distance of the first magnetic layer in the

10 {110} plane differs from that of the non-magnetic metal layer in the {111} plane by at least a particular value, in the vicinity of the interface between the first magnetic layer and the non-magnetic metal layer, while the atoms forming the first magnetic layer and the atoms forming the

15 non-magnetic metal layer are being aligned with each other, strains are generated in the individual crystal structures. That is, by generating the strain in the crystal structure of the first magnetic layer, the magnetostriction constant λ can be increased.

20   For example, when composed of Co_xFe_y (where $y \geq 20$ and $x+y=100$ are satisfied, and x and y are on an atomic percent basis), the first magnetic layer of the fixed magnetic layer may have a body-centered cubic (bcc) structure in which equivalent planes represented by the {110} plane are

25 oriented in the direction parallel to the interface. In addition, compared to Co or Co_xFe_y (where $y \leq 20$ and $x+y=100$ are satisfied) having an fcc structure, Co_xFe_y (where $y \geq 20$ and $x+y=100$ are satisfied) having a bcc structure has a

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large magnetostriction constant λ particularly at a composition in which y is approximately 50, and hence a larger magnetoelastic effect can be obtained. In addition, Co_xFe_y (where $y \geq 20$ and $x+y=100$ are satisfied) having a bcc

5   structure has a large coercive force, and hence the magnetization of the fixed magnetic layer can be tightly fixed.

In addition, in the present invention, the first magnetic layer of the fixed magnetic layer in the vicinity

10 of the interface at the non-magnetic metal layer side has a face-centered cubic (fcc) structure in which equivalent crystal planes represented by the {111} plane are oriented in the direction parallel to the interface at the non-magnetic metal layer side, and the first magnetic layer in

15 the vicinity of the interface at the non-magnetic interlayer side also has a body-centered cubic (bcc) structure in which equivalent crystal planes represented by the {110} plane are oriented in the direction parallel to the interface at the non-magnetic interlayer side.

20   When the first magnetic layer is formed to have a bcc structure in the vicinity of the interface at the non-magnetic interlayer side, the magnetostriction constant λ can be increased, and hence a large magnetoelastic effect can be obtained. On the other hand, when the first magnetic layer

25 is formed to have an fcc structure in the vicinity of the interface at the non-magnetic metal layer side, crystal orientations of the fixed magnetic layer, the non-magnetic material layer, and the free magnetic layer are likely to

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become uniform, and hence the rate (MR rate) of change in magnetoresistance can be increased.

For example, when the first magnetic layer of the fixed magnetic layer comprises Co_xFe_y (where $y \leq 20$ and $x+y=100$ are satisfied) or Co in the vicinity of the interface at the non-magnetic metal layer side and comprises Co_xFe_y (where $y \geq 20$ and $x+y=100$ are satisfied) in the vicinity of the interface at the non-magnetic interlayer side, an fcc structure can be formed in the vicinity of the interface at the non-magnetic metal layer side, in which equivalent planes represented by a {111} plane are oriented in the direction parallel to the interface, and a bcc structure can be formed in the vicinity of the interface at the non-magnetic interlayer side, in which equivalent planes represented by a {110} plane are oriented in the direction parallel to the interface.

In addition, if the first magnetic layer of the fixed magnetic layer comprises Co_xFe_y (where $y \geq 20$ and $x+y=100$ are satisfied) in the vicinity of the interface at the non-magnetic interlayer side, the RKKY interaction between the first magnetic layer and the other magnetic layer with the non-magnetic interlayer interposed therebetween is enhanced.

In the first magnetic layer of the fixed magnetic layer, the Fe content may be gradually increased from the interface at the non-magnetic metal layer side to that at the non-magnetic interlayer side.

According to the present invention, in order to generate the strain in the crystal structure while the atoms forming

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the non-magnetic metal layer and the atoms forming the first

magnetic layer are being aligned with each other, the

difference in nearest interatomic distance between the non-

magnetic metal layer and the first magnetic layer of the

5 fixed magnetic layer in a plane parallel to the interface

therebetween divided by the nearest interatomic distance of

the first magnetic layer is in the range of from 0.05 to

0.20.

In addition, the first magnetic layer comprises a

10 magnetic material having a positive magnetostriction

constant.

When the magnetic sensor of the present invention

further contains electrode layers composed of a film of

chromium (Cr), α-Ta, or Rh on side portions of the free

15 magnetic layer, the non-magnetic material layer, and the

fixed magnetic layer, a compressive stress applied to the

fixed magnetic layer in a track width direction (that is, a

tensile stress in the height direction) can be increased.

When a film of Cr, α-Ta, or Rh is used as described

20 above, the spacing of the crystal lattice of the electrode

layers in the direction parallel to a surface of the film is

0.2044 nm or more (the {110} spacing of a bcc structure),

0.2337 nm or more (the {110} spacing of a bcc structure), or

0.2200 nm or more (the {111} spacing of an fcc structure),

25 respectively.

In particular, the present invention can be used to

miniaturize the magnetic sensor, and the fixed magnetic

layer more has an optical track width dimension of 0.15 μm or

less.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a cross-sectional view of the structure of a magnetic sensor according to a first embodiment of the present invention, when it is viewed from a face opposing a recording medium;

Fig. 2 is a plan view of the magnetic sensor shown in Fig. 1;

Fig. 3 is a schematic view showing the state in which strains are generated while a non-magnetic metal layer and a fixed magnetic layer are being aligned with each other;

Fig. 4 is a schematic view showing the state in which a non-magnetic metal layer and a fixed magnetic layer are aligned with each other;

Fig. 5 is a schematic view showing the state in which a non-magnetic metal layer and a fixed magnetic layer are not aligned with each other;

Fig. 6 is a partial cross-sectional view of a fixed magnetic layer and its vicinity of a magnetic sensor of the present invention;

Fig. 7 is a partial cross-sectional view of a fixed magnetic layer and its vicinity of a magnetic sensor of the present invention;

Fig. 8 a partial cross-sectional view of a fixed magnetic layer and its vicinity of a magnetic sensor of the present invention;

Fig. 9 is a cross-sectional view of the structure of a

magnetic sensor according to a second embodiment of the
present invention, when it is viewed from a face opposing a
recording medium;

Fig. 10 is a graph showing the relationship between the
magnetostriction of a CoFe layer and the composition of a
PtMn layer obtained when the CoFe layer is provided on the
PtMn layer;

Fig. 11 is a graph showing the magnetostriction
constants of Co and CoFe obtained when a CoFe layer is
provided on a PtMn layer and when a Co layer is provided on
a PtMn layer;

Fig. 12 is a graph showing the magnetostriction
constants of Co and CoFe obtained when a PtMn layer is
provided on a CoFe layer and when a PtMn layer is provided
on a Co layer;

Fig. 13 is a graph showing the magnetostriction of a
multilayer film formed of a non-magnetic metal layer and a
ferromagnetic layer laminated thereon; and

Fig. 14 is a cross-sectional view showing the structure
of a related magnetic sensor when viewed from a face
opposing a recording medium.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 is a cross-sectional view of a magnetic sensor of
a first embodiment according to the present invention, when
it is viewed from a face opposing a recording medium.

In the magnetic sensor shown in Fig. 1, a multilayer
film T1 is formed on a lower gap layer 20 made of an

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insulating material such as alumina.

In the embodiment shown in Fig. 1, the multilayer film T1 is formed of a seed layer 21, a non-magnetic metal layer 22, a fixed magnetic layer 23, a non-magnetic material layer 24, a free magnetic layer 25, and a protective layer 26 laminated to each other in that order from the bottom.

The seed layer 21 is formed of an NiFe alloy, an NiFeCr alloy, Cr, Ta, or the like. The seed layer 21 is composed, for example, of 60 atomic percent of $(Ni_{0.8}Fe_{0.2})$ and 40 atomic percent of Cr and has a thickness of 35 to 60 Å.

When the seed layer 21 is provided, the {111} orientation of the non-magnetic metal layer 22 becomes superior. The non-magnetic metal layer 22 will be described later.

The fixed magnetic layer 23 has a synthetic ferrimagnetic structure composed of a first magnetic layer 23a and a second magnetic layer 23c with a non-magnetic interlayer 23b interposed therebetween. The magnetization of the fixed magnetic layer 23 is fixed in a height direction (Y direction in the figure) by the uniaxial anisotropy thereof.

The non-magnetic material layer 24 is a layer preventing magnetic coupling between the fixed magnetic layer 23 and the free magnetic layer 25 and is formed of a non-magnetic material, such as copper (Cu), Cr, gold (Au), or silver (Ag), having electrical conductivity. In particular, Cu is used. The thickness of the non-magnetic material layer is 17 to 30 Å.

The free magnetic layer 25 is formed of a magnetic material such as an NiFe alloy or a CoFe alloy. In the embodiment shown in Fig. 1, in particular, when the free magnetic layer 25 is formed of an NiFe alloy, a diffusion blocking layer (not shown) made of Co, CoFe, or the like is formed between the free magnetic layer 25 and the non-magnetic material layer 24. The thickness of the free magnetic layer 25 is 20 to 60 Å. In addition, the free magnetic layer 25 may have a synthetic ferrimagnetic structure composed of a plurality of magnetic layers laminated to each other with a non-magnetic interlayer interposed therebetween.

The protective layer 26 is formed, for example, of Ta and suppresses the progress of oxidation of the multilayer film T1. The thickness of the protective layer 26 is 10 to 50 Å.

In the embodiment shown in Fig. 1, on the side portions of the multilayer film T1 formed of the layers from the seed layer 21 to the protective layer 26, bias underlying layers 27, hard bias layers 28, and electrode layers 29 are formed. Using a longitudinal bias magnetic field from the hard bias layers 28, the magnetization of the free magnetic layer 25 is oriented in a track width direction (X direction in the figure).

The bias underlying layers 27 are formed of Cr, tungsten (W), or titanium (Ti); the hard bias layers 28 are formed, for example, of a cobalt-platinum (Co-Pt) alloy or a cobalt-chromium-platinum (Co-Cr-Pt) alloy; and the electrode layers

29 are formed of Cr, Ta, Rh, Au, or W.

The thickness of the bias underlying layer 27 is 20 to 100 Å; the thickness of the hard bias layer 28 is 100 to 400 Å; and the thickness of the electrode layer 29 is 400 to

5   1,500 Å.

On the electrode layers 29 and the protective layer 26, an upper gap layer 30 made of an insulating material such as alumina is provided. Although not shown in the figure, under the lower gap layer 20, a bottom shield layer is

10   provided, and on the upper gap layer, a top shield layer is provided. The top and the bottom shield layers are formed of a soft magnetic material such as NiFe. The thickness of each of the upper and the lower gap layers is 50 to 300 Å.

The magnetization of the free magnetic layer 25 is

15   oriented in the track width direction (X direction in the figure) by the longitudinal bias magnetic field from the hard bias layers 28. In addition, with respect to a signal magnetic field (external magnetic field) from a recording medium, the magnetization of the free magnetic layer 25 is

20   sensitive and changed in response to a relatively small signal magnetic field. On the other hand, the magnetization of the fixed magnetic layer 23 is fixed in the height direction (Y direction in the figure).

In accordance with the relationship between the change

25   in magnetization direction of the free magnetic layer 25 and the fixed magnetization direction (in particular, fixed magnetization direction of the second magnetic layer 23c) of the fixed magnetic layer 23, the electrical resistance will

be changed. The change in the electrical resistance above causes a change in voltage or in current, thereby permitting a leak magnetic field from a recording medium to be detected.

Features of this embodiment will be described.

5   The fixed magnetic layer 23 of the magnetic sensor shown in Fig. 1 has a synthetic ferrimagnetic structure formed of the first magnetic layer 23a and the second magnetic layer 23c with the non-magnetic interlayer 23b interposed therebetween. The magnetization of the first magnetic layer

10 23a and the magnetization of the second magnetic layer 23c are oriented antiparallel to each other by the RKKY interaction through the non-magnetic interlayer 23b.

The first magnetic layer 23a is disposed at a position further from the non-magnetic material layer 24 than the

15 second magnetic layer 23c. The first magnetic layer 23a is also in contact with the non-magnetic metal layer 22.

The non-magnetic metal layer 22 is formed of an X-Mn alloy (where X is at least one element selected from the group consisting of Pt, Pd, Ir, Rh, Ru, Os, Ni, and Fe).

20   ·   The thickness of the non-magnetic metal layer 22 is 5 to 50 Å.

When the non-magnetic metal layer 22 which is formed of an X-Mn alloy (where X is at least one element selected from the group consisting of Pt, Pd, Ir, Rh, Ru, Os, Ni, and Fe)

25 has a thickness as described above, the non-magnetic metal layer 22 continuously maintains a face-centered cubic structure (fcc) which is formed during film formation. When the thickness of the non-magnetic metal layer 22 is more

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than 50 Å, and when a temperature of 250°C or more is applied thereto, the crystal structure of the non-magnetic metal layer 22 is disadvantageously transformed into a CuAuI type regular face-centered tetragonal (fct) structure.

5   However, although the thickness of the non-magnetic metal layer 22 is more than 50 Å, when a temperature at 250°C or more is not applied thereto, the crystal structure of the non-magnetic metal layer continuously maintains a face-centered cubic (fcc) structure which is formed during

10   formation of the film.

When the non-magnetic metal layer 22, which is formed of an X-Mn alloy (where X is at least one element selected from the group consisting of Pt, Pd, Ir, Rh, Ru, Os, Ni, and Fe), has a face-centered cubic (fcc) structure, an exchange

15   coupling magnetic field is not generated at the interface between this non-magnetic metal layer 22 and the first magnetic layer 23a, or even when generated, the exchange coupling magnetic field is extremely weak, and as a result, the magnetization direction of the first magnetic layer 23a

20   cannot be fixed by the exchange coupling magnetic field.

Accordingly, in the magnetic sensor shown in Fig. 1, the magnetization of the fixed magnetic layer 23 is fixed by the uniaxial anisotropy thereof. The magnetic sensor shown in Fig. 1 is called a self-fixed type magnetic sensor.

25   The self-fixed type magnetic sensor can reduce a shunt loss as compared to that of a magnetic sensor provided with an antiferromagnetic layer having a large thickness of approximately 200 Å, and hence the magnetic field detection

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output of the magnetic sensor can be improved by 20% to 30%.
In addition, since the distance between the shield layers
provided at the top and the bottom sides of the magnetic
sensor can be decreased, the trend toward higher recording
5   density of a recording medium can also be satisfied.

In this embodiment, the thickness of the second magnetic
layer 23c is larger than that of the first magnetic layer
23a. The magnetization of the second magnetic layer 23c is
oriented in the height direction (Y direction in the figure),
10   and the magnetization of the first magnetic layer 23a is
fixed in the direction antiparallel to the height direction.

The thickness of the first magnetic layer 23a is 10 to
30 Å, and the thickness of the second magnetic layer 23c is
15 to 35 Å. When the thickness of the first magnetic layer
15   23a is increased, the coercive force is increased. However,
when the thickness of the first magnetic layer 23a is
increased, the shunt loss is also increased. In addition,
as described later, when the first magnetic layer 23a is
aligned with the non-magnetic metal layer 22, a strain is
20   generated in the crystal structure. This strain causes the
magnetostriction constant λ and the uniaxial anisotropy to be
increased. However, when the thickness of the first
magnetic layer 23a is increased too much, dislocations and
other defects cause the strain generated in the first
25   magnetic layer 23a to become small. As a result, the
magnetostriction constant λ and the uniaxial anisotropy are
decreased.

In the present invention, of the induced magnetic

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anisotropy and the magnetoelastic effect, which determine
the uniaxial anisotropy fixing the magnetization of the
fixed magnetic layer 23, the magnetoelastic effect is
primarily exploited.

5   The magnetoelastic effect is controlled by the
magnetoelastic energy. The magnetoelastic energy is defined
by a stress σ applied to the fixed magnetic layer 23 and the
magnetostriction constant λ thereof.

        Fig. 2 is a plan view showing the magnetic sensor in Fig.
10 1 when it is viewed from above in the figure (along the
direction opposite to the Z direction in the figure). The
multilayer film T1 is formed between a pair of the bias
underlying layers 27, a pair of the hard bias layers 28, and
a pair of the electrode layers 29. The bias underlying
15 layers 27 and the hard bias layers 28 are not shown in Fig.
2 as they are provided under the respective electrode layers
29. The peripheries of the multilayer film T1, the bias
underlying layers 27, the hard bias layers 28, and the
electrode layers 29 are covered with an insulating material
20 layer 31 shown by oblique lines.

        In addition, an end surface F located at a face opposing
a recording medium, which is composed of the multilayer film
T1, the bias underlying layers 27, the hard bias layers 28,
and the electrode layers 29, is exposed or is covered with a
25 protective layer of diamond-like carbon (DLC) having a small
thickness of 20 to 50 Å, that is, the end surface F is an
open end surface.

        Accordingly, since the end surface F is open, the

symmetry of stresses from the lower gap layer 20 and the upper gap layer 30 is destroyed, the stresses being originally isotropic in two-dimensions, and as a result, a tensile stress is applied to the multilayer film T1 in the

5 direction parallel to the height direction (Y direction in the figure). In addition, when each laminate film formed of the bias underlying layer 27, the hard bias layer 28, and the electrode layer 29 has an internal compressive stress therein, since the electrode layer and the like tends to

10 extend in the direction along the plane, a compressive stress parallel to the track width direction (X direction in the figure) and a compressive stress antiparallel thereto are applied to the multilayer film T1.

That is, tensile stress in the height direction and

15 compressive stresses in the track width direction are applied to the fixed magnetic layer 23 (which is open at the end surface F located at the face opposing the recording medium). In addition, since the first magnetic layer 23a is formed of a magnetic material having a positive

20 magnetostriction constant, the magnetoelastic effect causes the easy magnetization axis of the first magnetic layer 23a to be oriented parallel to a depth direction (height direction, Y direction in the figure) of the magnetic sensor. The magnetization direction of the first magnetic layer 23a

25 is thus fixed in a direction parallel or antiparallel to the height direction. The magnetization of the second magnetic layer 23c is fixed in a direction antiparallel to the magnetization direction of the first magnetic layer 23a by

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the RKKY interaction through the non-magnetic interlayer 23b.

In the present invention, the magnetoelastic energy is increased by increasing the magnetostriction constant of the fixed magnetic layer 23, and hence the uniaxial anisotropy

5 thereof is enhanced. When the uniaxial anisotropy of the fixed magnetic layer 23 is enhanced, the magnetization thereof is tightly fixed in a predetermined direction. This increases the output of the magnetic sensor, thereby improving the stability and the symmetry of the output.

10 In particular, since the first magnetic layer 23a forming the fixed magnetic layer 23 is in contact with the non-magnetic metal layer 22, a strain is generated in the crystal structure of the first magnetic layer 23a, and hence the magnetostriction constant λ thereof is increased.

15 As described above, the non-magnetic metal layer 22 has an fcc structure in which equivalent crystal planes represented by the {111} plane are oriented in the direction parallel to the interface.

In addition, when formed of Co or Co_xFe_y (where $y \leq 20$ and

20 $x+y=100$ are satisfied), the first magnetic layer 23a of the fixed magnetic layer 23 has a face-centered cubic (fcc) structure. In such a first magnetic layer 23a, equivalent crystal planes represented by the {111} plane are oriented in the direction parallel to the interface. Co_xFe_y where $y \leq 20$

25 and $x+y=100$ are satisfied and has an fcc structure will herein be referred to as fcc Co_xFe_y.

Accordingly, atoms forming the first magnetic layer 23a and atoms forming the non-magnetic metal layer 22 are likely

to be aligned with each other, and the crystal of the non-magnetic metal layer 22 and the crystal of the fixed magnetic layer 23 are placed in an epitaxial state.

However, the nearest interatomic distance of the first magnetic layer 23a in the {111} plane must be different from that of the non-magnetic metal layer 22 in the {111} plane by at least a particular value.

In order to increase the magnetostriction constant of the first magnetic layer 23a by generating a strain in the crystal structure while the atoms forming the non-magnetic metal layer 22 and the atoms forming the first magnetic layer 23a are aligned with each other, the composition of the non-magnetic metal layer 22 is adjusted. More specifically, the X element content of the X-Mn alloy, either of which may be used as a material for the non-magnetic metal layer 22, is adjusted.

For example, when the X element content of the X-Mn alloy is set to 51 atomic percent or more, the magnetostriction of the first magnetic layer 23a aligned with the non-magnetic metal layer 22 is rapidly increased. In addition, when the X element content of the X-Mn alloy is 55 to 99 atomic percent, the magnetostriction of the first magnetic layer 23a becomes stable while having a large value.

In addition, the value (hereinafter referred to as a "mismatch value") obtained by dividing the difference between the nearest interatomic distance of the non-magnetic metal layer 22 in the {111} plane and that of the first magnetic layer 23a in the {111} plane by the nearest

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interatomic distance of the first magnetic layer 23a in the
{111} plane is set in the range of from 0.05 to 0.20.

In the magnetic sensor of this embodiment, as
schematically shown in Fig. 3, while the atoms forming the
5   non-magnetic metal layer 22 and the atoms forming the first
magnetic layer 23a are being aligned with each other,
strains are generated in the individual crystal structures
in the vicinity of the interface therebetween.

In Fig. 3, N1 indicates the nearest interatomic distance
10   of the first magnetic layer 23a in the {111} plane, and N2
indicates the nearest interatomic distance of the non-
magnetic metal layer 22 in the {111} plane. N1 and N2 are
each measured at a place located far enough from the
interface between the non-magnetic metal layer 22 and the
15   first magnetic layer 23a so that the influence of the strain
is not significant.

As described above, when a strain is generated in the
crystal structure of the first magnetic layer 23a, the
magnetostriction constant λ thereof can be increased, and as
20   a result, a large magnetoelastic effect can be obtained.

As schematically shown in Fig. 4, when the atoms of the
non-magnetic metal layer 22 and the atoms of the first
magnetic layer 23a are aligned with each other and the
mismatch value between the non-magnetic metal layer 22 and
25   the first magnetic layer 23a is too small, strains are not
generated in the individual crystal structures in the
vicinity of the interface therebetween. As a result, the
magnetostriction constant λ of the first magnetic layer 23a

is not increased.

On the other hand, when the mismatch value between the non-magnetic metal layer 22 and the first magnetic layer 23a is too large, as schematically shown in Fig. 5, dislocations are formed and the atoms of the non-magnetic metal layer 22 and the atoms of the first magnetic layer 23a are not aligned with each other at all. As a result, a non-aligned state (or non-epitaxial state) is formed. When the atoms of the non-magnetic metal layer 22 and the atoms of the first magnetic layer 23a are placed in a non-aligned state, similar to the case of the mismatch value being too small, strains are also not generated in the individual crystal structures in the vicinity of the interface therebetween. As a result, the magnetostriction constant λ of the first magnetic layer 23a is not increased.

In addition, the first magnetic layer 23a of the fixed magnetic layer 23 may have a body-centered cubic (bcc) structure in which equivalent crystal planes represented by the {110} plane are oriented in the direction parallel to the interface. For example, when formed of Co_xFe_y (where $y \geq 20$ and $x+y=100$ are satisfied), the first magnetic layer 23a of the fixed magnetic layer 23 has a body-centered cubic (bcc) structure. Co_xFe_y where $y \geq 20$ and $x+y=100$ are satisfied and has a bcc structure will herein be referred to as bcc Co_xFe_y.

As described above, the non-magnetic metal layer 22 has an fcc structure in which equivalent crystal planes represented by the {111} plane are oriented in the direction

parallel to the interface.

The atomic arrangement of a crystal having a bcc structure in equivalent crystal planes represented by the {110} plane is similar to the atomic arrangement of a

5 crystal having an fcc structure in equivalent crystal planes represented by the {111} plane, and hence the crystal having a bcc structure and the crystal having an fcc structure can be placed in an aligned state, that is, in a so-called heteroepitaxial state in which the individual atoms are

10 aligned with each other.

In addition, the nearest interatomic distance of the first magnetic layer 23a in the {110} plane is different from that of the non-magnetic metal layer 22 in the {111} plane by at least the particular value. Hence, in the

15 vicinity of the interface between the first magnetic layer 23a and the non-magnetic metal layer 22, while the atoms forming the first magnetic layer 23a and the atoms forming the non-magnetic metal layer 22 are being aligned with each other, strains are generated in the individual crystal

20 structures. Hence, by generating a strain in the crystal structure of the first magnetic layer 23a, the magnetostriction constant λ thereof can be increased.

In addition, compared to Co (which has an fcc structure or fcc Co_xFe_y, bcc Co_xFe_y has a large magnetostriction

25 constant λ, particularly at a composition in which Y is approximately 50, and hence a larger magnetoelastic effect can be obtained. In addition, bcc Co_xFe_y has a large coercive force, and hence the magnetization of the fixed

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magnetic layer 23 can be tightly fixed.

In the present invention, in the vicinity of the interface between the first magnetic layer 23a and the non-magnetic metal layer 22, the atoms forming the first magnetic layer 23a and the atoms forming the non-magnetic metal layer 22 may be mostly aligned with each other to form an aligned state. For example, as schematically shown in Fig. 3, there may be some regions in which some atoms forming the first magnetic layer 23a and some atoms forming the non-magnetic metal layer 22 are not aligned with each other.

In addition, as a material for the second magnetic layer 23c, either bcc Co_xFe_y or Co or fcc Co_xFe_y may be used. When bcc Co_xFe_y is used as a material for the second magnetic layer 23c, positive magnetostriction can be increased. Bcc Co_xFe_y has a large coercive force and can tightly fix the magnetization of the fixed magnetic layer 23. In addition, the RKKY interaction between the first magnetic layer 23a and the second magnetic layer 23c with the non-magnetic interlayer 23b interposed therebetween is enhanced.

On the other hand, since being in contact with the non-magnetic material layer 24 and having a significant influence on the magnetoresistive effect, when the second magnetic layer 23c is formed of Co or fcc Co_xFe_y, the magnetoresistive effect is unlikely to be degraded.

Figs. 6 to 8 are partial cross-sectional views each showing other embodiments of the fixed magnetic layer 23.

As shown in Fig. 6, the first magnetic layer 23a forming

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the fixed magnetic layer 23 may be formed of an fcc magnetic

sublayer 23a1 provided at the non-magnetic metal layer 22

side and a bcc magnetic sublayer 23a2 provided at the non-

magnetic interlayer 23b side.

5   The fcc magnetic sublayer 23a1 has a face-centered cubic

(fcc) structure and is a magnetic layer in which equivalent

crystal planes represented by the {111} plane are oriented

in the direction parallel to the interface, and the bcc

magnetic sublayer 23a2 has a body-centered cubic (bcc)

10   structure and is a magnetic layer in which equivalent

crystal planes represented by the {110} plane are oriented

in the direction parallel to the interface.

       The fcc magnetic sublayer 23a1 may be formed using Co or

fcc Co_xFe_y, and the bcc magnetic sublayer 23a2 may be formed

15   using bcc Co_xFe_y.

       When the first magnetic layer 23a is formed to have a

bcc structure in the vicinity of the interface at the non-

magnetic interlayer 23b side, the magnetostriction constant λ

can be increased, and hence a large magnetoelastic effect

20   can be obtained. In addition, when the composition at the

non-magnetic interlayer 23b side is bcc Co_xFe_y, the RKKY

interaction between the first magnetic layer 23a and the

second magnetic layer 23c with the non-magnetic interlayer

23b interposed therebetween is enhanced.

25   In addition, when the first magnetic layer 23a is formed

to have an fcc structure in the vicinity of the interface at

the non-magnetic metal layer 22 side, the crystal

orientations of the fixed magnetic layer 23, the non-

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magnetic material layer, and the free magnetic layer becomes
uniform, and the size of the crystal grains can also be
increased, thereby increasing the rate (MR rate) of change
in magnetoresistance.

5   In addition, as shown in Fig. 7, the second magnetic
layer 23c forming the fixed magnetic layer 23 may be formed
of an fcc magnetic sublayer 23c2 provided at the non-
magnetic material layer 24 side and a bcc magnetic sublayer
23c1 provided at the non-magnetic interlayer 23b side.

10   The fcc magnetic sublayer 23c2 has a face-centered cubic
(fcc) structure and is a magnetic layer in which equivalent
crystal planes represented by the {111} plane are oriented
in the direction parallel to the interface, and the bcc
magnetic sublayer 23c1 has a body-centered cubic (bcc)

15   structure and is a magnetic layer in which equivalent
crystal planes represented by the {110} plane are oriented
in the direction parallel to the interface.

          As in the above first magnetic layer 23a, the second
magnetic layer 23c may be formed such that the fcc magnetic

20   sublayer 23c2 may be formed of Co or fcc Co_xFe_y, and the bcc
magnetic layer 23c1 may be formed of bcc Co_xFe_y.

          When the second magnetic layer 23c is formed to have a
bcc structure in the vicinity of the interface at the non-
magnetic interlayer 23b side, the magnetostriction constant λ

25   can be increased, and hence a large magnetoelastic effect
can be obtained.   In addition, when the composition at the
non-magnetic interlayer 23b side is bcc Co_xFe_y, the RKKY
interaction between the first magnetic layer 23a and the

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second magnetic layer 23c with the non-magnetic interlayer 23b interposed therebetween·is enhanced.

In addition, when the first magnetic layer 23a is formed to have an fcc structure in the vicinity of the interface at
5 the non-magnetic metal layer 22 side, degradation of magnetoresistive effect can be suppressed.

In addition, as shown in Fig. 8, the first magnetic layer 23a forming the fixed magnetic layer 23 may be formed of the fcc magnetic sublayer 23a1 provided at the non-
10 magnetic metal layer 22 side and the bcc magnetic sublayer 23a2 provided at the non-magnetic interlayer 23b side, and the second magnetic layer 23c may be formed of the fcc magnetic sublayer 23c2 provided at the non-magnetic material layer 24 side and the bcc magnetic sublayer 23c1 provided at
15 the non-magnetic interlayer 23b side.

As shown in Figs. 6 to ·8, the first magnetic layer 23a has a structure formed of a fcc magnetic sublayer 23a1 and a bcc magnetic sublayer 23a2 laminated to each other, and in addition, the second magnetic layer 23c has a structure
20 formed of a bcc magnetic sublayer 23c1 and a fcc magnetic sublayer 23c2 laminated to each other.

However, in the present invention, the first magnetic layer 23a of the fixed magnetic layer 23 may have an fcc structure in the vicinity of the interface at the non-
25 magnetic metal layer 22 side and a bcc structure in the vicinity of the interface at the non-magnetic interlayer 23b side. Accordingly, the first magnetic layer 23a may be formed such that in the vicinity of the interface at the

non-magnetic metal layer 22 side, the first magnetic layer 23a is Co or fcc Co_xFe_y. The Fe content of the first magnetic layer 23a may be gradually increased from the interface at the non-magnetic metal layer 22 side to that at

5   the non-magnetic interlayer 23b side such that in the vicinity of the interface at the non-magnetic interlayer 23b side the first magnetic layer 23a is bcc Co_xFe_y.

Similar to the composition of the first magnetic layer 23a, the second magnetic layer 23c may also be formed of a

10   CoFe alloy in which the Fe content is gradually increased from the interface at the non-magnetic material layer 24 side to that at the non-magnetic interlayer 23b side.

Fig. 9 is a cross-sectional view showing a magnetic sensor of a second embodiment according to the present

15   invention, when it is viewed from a face opposing a recording medium.

The magnetic sensor shown in Fig. 9 is similar to the magnetic sensor shown in Fig. 1, and instead of the multilayer film T1, the structure in which a multilayer film

20   T2 is formed is different from that of the magnetic sensor shown in Fig. 1. The multilayer film T2 is formed of the seed layer 21; free magnetic layer 25; the non-magnetic material layer 24; the fixed magnetic layer 23 composed of the second magnetic layer 23c, the non-magnetic interlayer

25   23b, and the first magnetic layer 23a; the non-magnetic metal layer 22; and the protective layer 26 laminated to each other in that order from the bottom. That is, the multilayer film T2 has the structure in which the

constituent layers thereof are laminated to each other in the order opposite to that in the multilayer film T1.

In the magnetic sensor of this embodiment, the first magnetic layer 23a of the fixed magnetic layer 23 is also in contact with the non-magnetic metal layer 22.

In this embodiment, the crystal structure of the non-magnetic metal layer 22 also continuously maintains a face-centered cubic (fcc) structure which is formed during formation of the film.

Accordingly, the atoms forming the non-magnetic metal layer 22 and the atoms forming the first magnetic layer 23a of the fixed magnetic layer 23 are aligned with each other, and hence the crystal of the non-magnetic metal layer 22 and the crystal of the first magnetic layer 23a of the fixed magnetic layer 23 is placed in an epitaxially aligned state.

In addition, the nearest interatomic distance of the first magnetic layer 23a in the {111} plane or in the {110} plane is different from that of the non-magnetic metal layer 22 in the {111} plane by at least the particular value. Hence, in the vicinity of the interface between the first magnetic layer 23a and the non-magnetic metal layer 22, while the atoms forming the first magnetic layer 23a and the atoms forming the non-magnetic metal layer 22 are being aligned with each other, strains are generated in the individual crystal structures. Accordingly, since the strain is generated in the crystal structure of the first magnetic layer 23a, the magnetostriction constant λ thereof can be increased.

In order to increase the anisotropy based on the magnetoelastic effect of the fixed magnetic layer 23, compressive stresses are increased which are applied to the multilayer film T1 or T2 in the directions parallel and antiparallel to the track width direction from the bias underlying layers 27, the hard bias layers 28, and the electrode layers 29.

For example, when the electrode layers 29 are composed of a film of Cr (bcc), α-Ta (bcc), or Rh (fcc), and when the spacing of the crystal lattice plane of the electrode layers 29 in the direction parallel to a surface of the film is 0.2044 nm or more, 0.2337 nm or more, or 0.2200 nm or more, respectively, the compressive stresses applied to the multilayer film T1 or T2 can be increased. In this case, in the direction indicated by the arrows shown in Fig. 2, that is, in directions outside the electrode layers 29, the electrode layers 29 are extended, and hence compressive stresses are applied to the multilayer film T1 or T2 in the directions parallel and antiparallel to the track width direction (X direction in the figure).

The spacing of the crystal lattice of the electrode layers 29 in the direction parallel to the film surface can be measured using X-ray diffraction or electron beam diffraction. In addition, the spacing of the crystal lattice of bulk Cr, bulk α-Ta, or bulk Rh in the direction parallel to a film surface thereof is 0.2040 nm, 0.2332 nm, or 0.2196 nm, respectively. When the spacing is not less than that described above, the electrode layers 29 start to

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apply the compressive stresses to the multilayer film T1 or T2.

When the electrode layers 29 are formed using Cr and a soft metal material such as Au, the compressive stresses described above are as follows. For films formed by a bias underlying layer of Cr (50 Å), a hard bias underlying layer of CoPt (200 Å), an interlayer of Ta (50 Å), an electrode layer, and a protective layer of Ta (50 Å) laminated to each other in that order from the bottom: when the electrode layer is Au (800 Å), a compressive stress of 280 MPa is generated, while when the electrode layer is Cr (1,400 Å), a compressive stress of 670 MPa is generated.

Although not shown in Fig. 1, the interlayer Ta (50 Å) and the protective layer Ta (50 Å) serve as layers for regulating the orientation of the electrode layer and preventing oxidation, respectively.

When the electrode layers 29 are formed by sputtering, ion beam sputtering is used; and the pressure of Ar, Xe, Kr, or the like in a sputtering machine is reduced to 5×10^{-3} to 1×10^{-1} (Pa). When the pressure of Ar, Xe, Kr, or the like in a sputtering machine is low, the probability in which Cr, Ta, or Rh atoms forming the electrode layer collide with Ar atoms is decreased, and hence atoms such as Cr are deposited while a high energy thereof is maintained. When Cr atoms sputtered from a target or the like collide against a Cr film previously formed with high energy and are then buried therein, the electrode layers 29 are extended outside.

The magnetization directions of the side portions of the

fixed magnetic layer 23 in the track width direction are

liable to be inclined by a longitudinal bias magnetic field

generated by the hard bias layers 28. However, large

compressive stresses are applied to the side portions of the

5   fixed magnetic layer 23 in the track width direction.

Accordingly, the anisotropy is increased by the

magnetoelastic effect at the side portions of the fixed

magnetic layer 23 in the track width direction, and as a

result, the magnetization directions are tightly fixed in

10   one direction.

    According to the present invention, the magnetization

direction of the fixed magnetic layer 23 is fixed by the

uniaxial anisotropy based on the relationship between the

magnetostriction and the compressive stresses from the side

15   portions of the fixed magnetic layer 23. The compressive

stresses applied to the fixed magnetic layer 23 at the side

portions in an optical track width direction are high, and

the compressive stress applied thereto at the central

portion is low. Hence, when the width dimension of the

20   fixed magnetic layer 23 in the optical track width direction

is large, the force fixing the magnetization direction of

the fixed magnetic layer 23 at the central portion is

decreased. Accordingly, an optical track width dimension W1

of the fixed magnetic layer 23 is 0.15 μm or less.

25   In addition, the magnetostriction of the free magnetic

layer 25 has a negative magnetostriction constant. As

described above, since the compressive stresses are applied

to the multilayer film T1 of the magnetic sensor from side

portions thereof, by the magnetoelastic effect, the free

magnetic layer 25 having a negative magnetostriction

constant has an easy magnetization axis which is parallel or

antiparallel to the track width direction.

5   The magnetizations of the free magnetic layer 25 at the

side portions in the track width direction may be

unstablized due to demagnetizing fields. However, the side

portions of the free magnetic layer 25 in the track width

direction are close to the hard bias layers 28, and hence

10   large compressive stresses are applied to the side portions

of the free magnetic layer 25. Accordingly, at the side

portions of the free magnetic layer 25 in the track width

direction, the anisotropy by the magnetoelastic effect is

increased, and as a result, the magnetization direction is

15   stabilized.

Hence, even when the thicknesses of the hard bias layers

28 are decreased so as to decrease the longitudinal bias

magnetic field, the free magnetic layer 25 may be placed in

a stable single domain state. When the longitudinal bias

20   magnetic field can be decreased by decreasing the

thicknesses of the hard bias layers 28, the magnetization

state of the fixed magnetic layer 23 fixed in the height

direction can be stabilized.

In addition, since the compressive stress in the

25   vicinity of the central portion of the free magnetic layer

25 is low compared to that at each of the side portions

thereof, the decrease in magnetic field detection

sensitivity can be suppressed.

The magnetostriction constant λ of the free magnetic layer 25 is in the range of from -8×10^{-6} to -0.5×10^{-6}. In addition, the thickness t of the hard bias layers 28 is in the range of from 100 to 200 Å. When the magnetostriction

5   constant λ of the free magnetic layer 25 is too small, or the thickness of the hard bias layers 28 is too large, reproduction sensitivity of the magnetic sensor is degraded. On the other hand, when the magnetostriction constant λ of the free magnetic layer 25 is too large, or the thickness t

10   of the hard bias layers 28 is too small, reproduction waveform of the magnetic sensor is liable to be distorted.

The magnetic sensors of the embodiments shown in Figs. 1 and 9 are manufactured by thin-film formation using a sputtering or a deposition method and pattern formation

15   using resist photolithography. Generally known sputtering and resist photolithography may be used for forming the magnetic sensors of the embodiments.

However, in order to generate stresses in the individual crystal structures while the atoms forming the first

20   magnetic layer 23a and the atoms forming the non-magnetic metal layer 22 are being aligned with each other, when the non-magnetic metal layer 22 and the first magnetic layer 23a are formed, for example, the following conditions are used:

25   DC magnetron sputtering method

Input Power to Target: 10 to 100 W

Ar pressure: 0.01 to 0.5 Pa

Distance between Target and Substrate: 100 to 300 mm

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In addition, in forming the magnetic sensor shown in Fig. 1, when the substrate temperature used during formation of the first magnetic layer 23a is set higher than that used

5   during formation of the non-magnetic metal layer 22, due to thermal expansion, a larger strain can be generated in alignment. When the magnetic sensor shown in Fig. 9 is formed, the substrate temperature used during formation of the non-magnetic metal layer 22 is higher than that used

10   during formation of the first magnetic layer 23a.

After the magnetic sensor shown in Fig. 1, which is provided with the hard bias layers 28 at the side portions of the multilayer film T1, is formed, for example, a high magnetic field of 1,200 (KA/m) is applied in the height

15   direction, so that the magnetizations of the first magnetic layer 23a, the second magnetic layer 23c, and the hard bias layers 28 are oriented in the height direction. Subsequently, the applied magnetic field is continuously decreased so as to be smaller than a spin flop magnetic

20   field for the first magnetic layer 23a and the second magnetic layer 23c. As a result, the magnetizations of the first magnetic layer 23a and the second magnetic layer 23c are oriented antiparallel to each other. After the magnetic field applied in the height direction is removed, a magnetic

25   field larger than the coercive force of the hard bias layers 28 is applied in the track width direction, thereby magnetizing the hard bias layers 28.

When the magnetic field applied in the track width

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direction is removed, the magnetizations of the first magnetic layer 23a and the second magnetic layer 23c of the fixed magnetic layer 23 are oriented antiparallel or parallel to each other in the height direction, primarily

5 due to the magnetoelastic effect. In addition, the free magnetic layer 25 is placed in a single domain state in the track width direction due to the longitudinal bias magnetic field from the hard bias layers 28.

In addition, by applying a magnetic field in the height

10 direction when the fixed magnetic layer 23 is formed, the induced anisotropy may be imparted to the first magnetic layer 23a and the second magnetic layer 23c of the fixed magnetic layer 23.

However, when the optical track width dimension of the

15 fixed magnetic layer 23 is 0.15 µm or less, the influence of the magnetoelastic effect is significantly increased. In particular, in the present invention, since the magnetostriction constants λ of the first magnetic layer 23a and the second magnetic layer 23c and the compressive

20 stresses applied to the multilayer film T1 in the track width direction are increased, the magnetization of the fixed magnetic layer 23 is fixed primarily by the magnetoelastic effect.

In this embodiment, laminates that are each composed of

25 the hard bias layer 28 and the electrode layer 29 are formed on the side portions of each of the multilayer films T1 and T2. The laminates described above cause compressive stresses to be applied to the multilayer films T1 and T2.

However, the hard bias layers 28 do not have to be provided at the side portions of each of the multilayer films T1 and T2. For example, on the side portions of each of the multilayer films T1 and T2, laminates that are each composed
5   of a soft magnetic material layer and an antiferromagnetic layer may be provided, or only insulating layers may be provided.

In addition, the present invention may be applied to a tunnel magnetoresistive element and a CPP-GMR sensor, in
10   which a sense current flows in the direction perpendicular to the film thickness of each of the multilayer film T1 and T2. In this case, the electrode layers are formed at an upper side and a lower side of each of the multilayer film T1 and T2.

.15

EXAMPLES

The change in magnetostriction of CoFe was measured when the composition ratio of a PtMn layer of the laminate was changed, the laminate made of the PtMn layer and a CoFe
20   layer provided thereon.

A multilayer film having the following structure was formed and was then annealed at 290°C for four hours.

The multilayer film had the structure composed of alumina (1,000 Å), $(Ni_{0.8}Fe_{0.2})_{60}Cr_{40}$ (52 Å), Pt_xMn_{100-x} (30 Å),
25   $Co_{90}Fe_{10}$ (20 Å), and Ru (9 Å) provided in that order on a silicon substrate.

In this example, by omitting the second magnetic layer, the non-magnetic material layer, the free magnetic layer,

and the like, measurement of the magnetostriction of the first magnetic layer 23a was accurately performed.

For the measurement of the magnetostriction, an optical lever method was used. While the surface of the multilayer film described above was irradiated with laser beams, a magnetic field was applied to the multilayer film in the direction parallel to the film surface thereof. The deflection of the multilayer film caused by the magnetostriction was read as the change in reflection angle of the laser beams, and the magnetostriction constant of the multilayer film was obtained thereby.

The results are shown in Fig. 10. As shown in Fig. 10, as the Pt content of the PtMn layer was increased, the magnetostriction constant of the multilayer film was increased. In particular, as the Pt content increased from 51 atomic percent to 55 atomic percent, the magnetostriction constant rapidly increased. As the Pt content increased from 55 atomic percent, while the magnetostriction constant still increased, the rate of increase was lower.

The reason for these increases in the magnetostriction constant is believed to be that as the Pt content of the PtMn layer is increased, the crystal lattice constant of the PtMn is increased. As a result, a strain in the vicinity of the interface between the PtMn layer and the CoFe layer is increased.

Next, when a CoFe layer was provided on a PtMn layer, and a Co layer was provided on a PtMn layer, the magnetostriction constants of CoFe and Co were compared to

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each other.

A multilayer film was formed with a structure composed of: alumina (1,000 Å), $(Ni_{0.8}Fe_{0.2})_{60}Cr_{40}$ (52 Å), $Pt_{50}Mn_{50}$ (0 Å or 30 Å), PIN 1 (X Å), Ru (9 Å), Cu (85 Å), and Ta (30 Å) provided in that order on a silicon substrate (where the PIN 1 layer was $Co_{90}Fe_{10}$ or Co). The multilayer film was then annealed at 290°C for 4 hours.

An optical lever method was used for measuring the magnetostriction.

The results are shown in Fig. 11. In both cases in which Co and CoFe were used for forming the PIN 1 layer, when the PtMn layer was provided, the magnetostriction constant was large compared to the magnetostriction constant in structures in which the PtMn layer was not provided. In addition, when the PIN 1 layer was made of Co, the magnetostriction constant was larger than the magnetostriction constant obtained when CoFe was used.

As illustrated, when the PIN 1 layer was made of Co and the PtMn layer (30 Å) was provided under the PIN 1 layer, the magnetostriction constant increased as the thickness of the PIN 1 layer increased from 16 to 20 Å. However, when the thickness thereof was more than 20 Å, the magnetostriction constant decreased.

The results indicate that when the thickness of the PIN 1 layer is excessively large, the magnetostriction constant decreases. This decreases the benefits obtained by the strain generated in the vicinity of the interface between the PIN 1 layer and the PtMn layer.

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Next, a PtMn layer was provided on the PIN 1, and the magnetostriction constants of Co and CoFe were compared to each other.

A multilayer film was formed with a structure composed

5 of: alumina (1,000 Å), $(Ni_{0.8}Fe_{0.2})_{60}Cr_{40}$ (52 Å), Cu (85 Å), Ru (9 Å), PIN 1 layer (X Å), $Pt_{50}Mn_{50}$ (0 Å or 30 Å), and Ta (30 Å) provided in that order on a silicon substrate (where the PIN 1 was $Co_{90}Fe_{10}$ or Co). The multilayer film was then annealed at 290°C for 4 hours.

10 As above, an optical lever method was used for measuring the magnetostriction.

The results are shown in Fig. 12. When the PtMn layer was formed on the PIN 1 layer, the same tendency was obtained as that obtained when the PtMn layer was formed

15 under the PIN 1 layer.

That is, in both cases in which Co and CoFe were used for forming the PIN 1 layer, when the PtMn layer was provided, the magnetostriction constant was larger than that obtained when the PtMn layer was not provided. In addition,

20 when the PIN 1 layer was made of Co, the magnetostriction constant was larger than that obtained when CoFe was used. Furthermore, when the PIN 1 layer was made of Co and the PtMn layer (30 Å) was provided on the PIN 1 layer, the magnetostriction constant increased as the thickness of the

25 PIN 1 layer increased from 16 to 20 Å. However, when the thickness of the PIN 1 layer was more than 20 Å, the magnetostriction constant decreased.

Next, a PtMn layer and a multilayer film having a

synthetic ferrimagnetic structure were laminated to each
other, and the magnetostriction was measured. The
multilayer film had a structure composed of: alumina (1,000
Å), $(Ni_{0.8}Fe_{0.2})_{60}Cr_{40}$ (52 Å), $Pt_{50}Mn_{50}$ (30 Å), PIN 1 (16 Å), Ru
5   (9 Å), PIN 2 layer (40 Å), Cu (85 Å), and Ta (30 Å) provided
in that order on a silicon substrate (where the PIN 1 layer
and the PIN 2 layer were $Co_{90}Fe_{10}$, $Fe_{50}Co_{50}$, or Co). The
multilayer film was then annealed at 290°C for 4 hours.

In this embodiment, the thickness of the PIN 2 layer was
10 larger than the above thickness so that a spin flop magnetic
field between the PIN 1 and the PIN 2 layers was increased,
and hence the magnetostriction was easily measured.

A bending method was used for measuring the
magnetostriction. The bending method is a method in which a
15 uniaxial strain is applied to the multilayer film by bending
thereof. The magnetostriction constant is measured from the
change in uniaxial anisotropy caused by a reverse
magnetostriction effect.

The results are shown in Table 1.

20

Table 1

PIN 1	$Co_{90}Fe_{10}$	Co	$Fe_{50}Co_{50}$
PIN 2	$Co_{90}Fe_{10}$	Co	$Co_{90}Fe_{10}$
λ_s (ppm)	+13.6	+54.4	+29.5

From these results, it can be seen that when the PIN 1
layer and the PIN 2 layer are formed of Co, the
25 magnetostriction constant is large compared to that obtained

when CoFe is used.

Next, the thickness of the non-magnetic metal layer was changed, and the changes in magnetostriction constant of CoFe and Co were compared to each other.

5   A multilayer film with a structure composed of: alumina (1,000 Å), $(Ni_{0.8}Fe_{0.2})_{60}Cr_{40}$ (52 Å), non-magnetic metal layer, PIN 1 layer, Ru (9 Å), PIN 2 layer (40 Å), Cu (85 Å), and Ta (30 Å) provided in that order on a silicon substrate. The multilayer film was annealed at 290°C for 4 hours, and then

10   the magnetostriction was measured.

In this embodiment, by omitting the free magnetic layer and the like, the measurement of the magnetostriction of the fixed magnetic layer 23 was accurately performed.

In this example, the non-magnetic metal layer was Ru or

15    $Pt_{50}Mn_{50}$ (atomic percent); the PIN 1 layer was Co, $Co_{90}Fe_{10}$ (atomic percent), or $Fe_{50}Co_{50}$ (atomic percent); and the PIN 2 layer was Co or $Co_{90}Fe_{10}$ (atomic percent). Hereinafter, $Co_{90}Fe_{10}$ (atomic percent) and $Fe_{50}Co_{50}$ (atomic percent) will be simply referred to as "CoFe" and "FeCo", respectively.

20   For the measurement of the magnetostriction, the bending method described above was used. The results shown in Fig. 13 indicate that, regardless of whether the non-magnetic metal layer was formed of Ru or $Pt_{50}Mn_{50}$ (atomic percent), when the PIN 1 layer was formed Co or FeCo, the

25   magnetostriction constant was larger than that obtained when the PIN 1 layer was formed from CoFe. The reason for this may be that CoFe, unlike Co or FeCo, is a material in which the magnetostriction does not appreciably change, even when

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a strain is generated.

It can be seen that when the non-magnetic metal layer was formed, the magnetostriction was larger than that obtained when the non-magnetic metal layer was not formed. Also, when the PIN 1 layer was formed from Co, the increase in magnetostriction of the non-magnetic metal layer formed from Ru was equivalent to that of the non-magnetic metal layer formed from $Pt_{50}Mn_{50}$ (atomic percent). When the PIN 1 layer was formed from FeCo, the magnetostriction was larger when the non-magnetic metal layer was formed from $Pt_{50}Mn_{50}$ (atomic percent) than the magnetostriction obtained when the non-magnetic metal layer was formed from Ru.

In addition, when the PIN 1 layer was formed from Co or FeCo, and the thickness of the non-magnetic metal layer was approximately 5 Å or more, the magnetostriction constant gradually decreased as the thickness increased. The reason for may be that the interface between the non-magnetic metal layer and the PIN 1 layer is liable to be in a non-aligned state as the thickness of the non-magnetic metal layer is increased. In other words, when the thickness of the non-magnetic metal layer is decreased, the lattice constant of the non-magnetic metal layer is changed. As a result, the interface between the non-magnetic metal layer and the PIN 1 layer is correspondingly in an aligned state while a strain is generated.

In summary, a mechanism for controlling magnetostriction of a fixed magnetic layer in a magnetic sensor having a self-fixed magnetic layer is disclosed. Hence, when a

material for the non-magnetic metal layer which is in
contact with the fixed magnetic layer described above is
appropriately selected, a magnetic sensor can be provided
which appropriately controls the magnetostriction of the
5   fixed magnetic layer to tightly fix the magnetization
thereof.

In particular, the fixed magnetic layer is formed of a
plurality of magnetic layers with a non-magnetic interlayer
interposed therebetween. The plurality of magnetic layers
10   include a first magnetic layer, which is formed at a
position farthest from the non-magnetic material layer,
provided so as to be in contact with the non-magnetic metal
layer. The non-magnetic metal layer is composed of an X-Mn
alloy (where X is at least one selected from the group
15   consisting of Pt, Pd, Ir, Rh, Ru, Os, Ni, and Fe).

Using the structure described above, a strain can be
generated in the crystal structure of the first magnetic
layer, thereby increasing the magnetostriction constant λ
thereof. By increasing the magnetostriction constant of the
20   fixed magnetic layer, the magnetoelastic energy is increased,
and hence the uniaxial anisotropy of the fixed magnetic
layer can be increased.

When the uniaxial anisotropy of the fixed magnetic layer
is increased, the magnetization thereof is tightly fixed in
25   a predetermined direction, the output of the magnetic sensor
is increased, and the stability and the symmetry thereof are
also improved.

Although embodiments of the present invention were

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described above, various modifications can be applied

without deviating from the scope of the present invention.

The embodiments described above exemplify the present

invention, but do not serve to limit the present invention.

5   For example, although absolute numbers are given throughout

this disclosure, such as the compositions of the first and

second magnetic layers or the optical track width of the

pinned magnetic layer, deviations from these numbers are not

outside of the scope of the present invention